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AFCRL-63-407

A STUDY OF HIGH ALTITUDE  
WATER-VAPOR DETECTORS

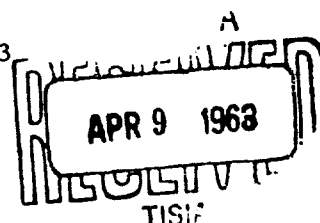
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SCIENTIFIC AND FINAL REPORT

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## ABSTRACT

This report describes the research and engineering required to prepare a sampling system for making water-vapor and index of refraction measurements in the atmosphere. It covers the instrumentation, equipment testing, flight description, and results of the flight, and includes conclusions and recommendations.

The purpose of the flight to 80,700 ft was to correlate data received from several different types of water-vapor indicators. These included four hygrometers (two alpha type and two optical type) and two gravimetric water-vapor traps (the Dual Molecular Sieve unit and Goldsmith Vapor Trap). In addition, two microwave refractometers were flown to see if the two units functioned properly under operational conditions and how their data compared with the hygrometer data in the lower altitudes.

Index of refraction data were obtained only from one unit: these followed published data for the first portion of the flight, but wandered radically during the latter half. The two alpha hygrometers functioned properly during ascent, but their data were erroneous because of contamination during float and descent. Their data are plotted in both graphical and tabular form. The Goldsmith Vapor Trap sampling was at a slower rate than expected but yielded a mixing ratio of  $0.09 \pm 0.01$  g per kg over an altitude range of 28 to 78 mb.

## TABLE OF CONTENTS

Section	Title	Page
	ABSTRACT	ii
I	INTRODUCTION	1
II	DISCUSSION OF SENSORS	1
	A. Water-Vapor Units	1
	1. Gravimetric Water-Vapor Collectors	2
	2. Hygrometer Units	2
	B. Refractometers	4
III	TESTING PROCEDURES	5
	A. Individual Testing	5
	B. Environmental Test	6
	C. Preflight Group Testing	8
IV	FLIGHT OPERATIONS	8
	A. Preflight Equipment Checks	8
	B. Launch Procedures and Flight	14
V	FLIGHT RESULTS	15
VI	CONCLUSIONS AND RECOMMENDATIONS	23
VII	PROJECT PERSONNEL	26
VIII	REFERENCES	27

## LIST OF ILLUSTRATIONS

Figure	Title	Page
1	Block Diagram of Airborne Instrumentation	9
2	Block Diagram of Ground Support Instrumentation	10
3	Arrangement of Sensors, Top View	12
4	Arrangement of Sensors, Side View	13
5	Refractometer Data	16
6	Comparison of Experimental and Calculated Index of Refraction, Frost Point, and Ambient Temperature Data	18
7	Frost-Point Data	20

## I. INTRODUCTION

This is the scientific and final report of research conducted by the Electronics Division of General Mills, Inc. for the Air Force Cambridge Research Laboratories, Office of Aerospace Research, under Contract No. AF 19(628)-483 during the period 1 May through 31 December 1962.

The objectives of this program were to prepare, test, and fly a balloon system, and to analyze data received. Comparisons of the frost points, as determined by each of four hygrometers, were planned as indications of the relative lag of each instrument, the search magnitude of individual sensors, and the reliability of their data. The mixing ratios determined by two gravimetric devices for the float altitude would also be compared. These ratios would in turn be compared to the frost-point values found at float altitude by the hygrometers.

Two refractometers were placed on the flight to check one against the other and, in the lower atmosphere, against the hygrometers. Another purpose was to determine whether they functioned properly under operational conditions. The data found were compared with existing profiles to determine fluctuations from the mean values previously reported.

We present in this report a discussion of the instruments, details of the testing, flight preparation, and flight results, and offer conclusions and recommendations.

## II. DISCUSSION OF SENSORS

Two different types of instruments were involved in this program. The first type measures water-vapor content in the atmosphere; the second type determines variations in the refractive index.

### A. Water-Vapor Units

The water-vapor devices used on the flight were of two distinct types; a gravimetric water collector, and a frost-point indicator. We discuss these

below, giving some differences in their operation but not elaborating on the instruments themselves, as this has been accomplished in literature by their manufacturers.

#### 1. Gravimetric Water-Vapor Collectors

There were two gravimetric water-vapor units on the flight. Both were built by General Mills, Inc.

The first unit was a Dual Molecular Sieve<sup>1</sup> unit that utilizes the principle of adsorption of water vapor on molecular sieve adsorbent. The prepared adsorbent (Type 13X, Linde Company, Tonawanda, New York) is placed in sealed canisters. At the desired sampling altitude, a high-volume blower flushes the sampling system. The adsorbent is then dropped into two 2-inch thick beds, and air is drawn through the beds. Water vapor and carbon dioxide are removed by the adsorbent, which is then dropped into canisters and sealed at altitude. A total of approximately 1 g of water is collected in this manner, after which two separate methods determine the amount of air sampled--a flowmeter, and the amount of carbon dioxide collected. The mixing ratio is then determined by dividing the amount of water collected by the weight of air sampled.

The Goldsmith Vapor Trap was built by General Mills, Inc. from plans of the original unit designed and flown by Goldsmith, et al<sup>2,3</sup> in the United Kingdom. This unit draws air, by means of a small-volume blower, through a coil of stainless steel tubing. This tubing is immersed in liquid nitrogen which freezes out the water vapor and carbon dioxide. The amount of water is approximately 50 mg in this unit, and the mixing ratio is determined in the same manner as that described above.

#### 2. Hygrometer Units

The four hygrometer units consisted of three types: the Peltier-cooled alpha radiation hygrometer developed by Minneapolis Honeywell, the Peltier-cooled optical hygrometer developed by Bendix Corporation, and the dry ice-alcohol cooled optical hygrometer of the Ballistic Research Laboratories.

The heart of the Honeywell system consists of a Peltier cooler, a radioactive source of alpha particles, and an alpha particle detector. An electronic amplifier completes the servo loop and a thermistor imbedded in the cooler measures the frost point. The Peltier cooler is a semiconductor device which heats or cools as a function of the direction of current flow through it. Within certain limits the temperature is proportional to current; therefore, if the dew point is detected, it is only necessary to control the current through the Peltier cooler to maintain the device at the dew-point temperature.

Polonium-210 serves as the radiation source and is mounted on the temperature-controllable surface of the Peltier cooler. The energy of the alpha particles emitted by the polonium is reduced by a thin film of moisture or frost, and this reduction is detected by the alpha particle detector which is placed 20 to 50 thousandths of an inch away. For reference, a second radiation source and detector are mounted adjacent to the first so that both experience the same environment. The reference source always remains at ambient temperature.

Identical amplifiers follow the two detectors to increase the pulse heights sufficiently to drive a flip-flop. Pulses from the two amplifiers are applied to opposite inputs on the flip-flop, which serves as a summing device. Only one of the two outputs is used; since it swings between two finite voltage levels, an average voltage exists which is a function of the on-off time. A low-pass filter, with a time constant adjusted to provide the desired sampling period, averages the error signal to nearly a dc voltage. This signal is fed into a difference amplifier or comparator. The mid-point of the flip-flop output is taken as the voltage reference. Dc amplification increases the error signal level, followed by a power amplifier to match the impedance of the Peltier cooler.

A pulse from the dew-point alpha particle detector trips the flip-flop into the state which provides the proper output to cause the Peltier cooler to cool, while a pulse from the reference detector triggers the flip-flop into the opposite state, causing the Peltier cooler to heat.

The Bendix unit also utilizes as its cold source a Peltier cooler with a thermistor embedded in it to determine frost point. The control system in

this unit is an optical one. A light beam is reflected from a mirror that is mounted on the cooler. When the cooler is at the frost-point temperature, frost forms, the light beam is interrupted, the cooler is turned off, and the heating cycle is turned on. After the heater has removed the frost, the light beam is again complete, and the cycle is repeated.

The Ballistic Research Laboratories unit utilizes a constant cold source of dry ice-alcohol or, as in our case, frozen ethyl alcohol. A mirror is attached to the end of a rod that is immersed in the cold bath. The mirror contains a thermistor and a heater--the thermistor measures frost point as above, and the heater clears the mirror of frost when required. An optical system is used to control the heating cycle. A light source reflects a beam of light off the mirror onto a photocell. When frost is formed on the mirror, the heater is turned on until the frost is removed and the light path is again unobstructed. The heater is then turned off, and the cycle is repeated.

The main difference between the units is that the cold source is continuously on in the Ballistic Research Laboratories unit but cycles on and off in the other two units. The Ballistic Research Laboratories unit is also fan ventilated whereas the other two use ram ventilation.

In each of the above hygrometers, the thermistor is fed into an output system to record the frost point. These units are continuous-reading devices.

#### B. Refractometers

In the flight train were two refractometers of the microwave type designed and manufactured by Bendix Corporation. This unit pulls air through a tube which contains the sampling capacitor. The capacitor is part of a microwave circuit in the 20 Mc range. As the index of refraction changes, the value of the capacitor changes, causing a change in basic frequency. This signal is beat against a stable frequency of the same magnitude in the refractometer. The difference frequency is a representation of the index of refraction. A temperature correction must be applied to the result obtained from the output frequency to obtain the true index of refraction at any point.

### III. TESTING PROCEDURES

Prior to the flight, all sensors underwent three separate test situations-- individual, environmental, and preflight group testing.

#### A. Individual Testing

As each hygrometer was received, it was tested to determine whether the instrument was functioning according to manufacturer's specifications. With the proper input voltages, the output of each hygrometer was monitored to determine the range and type of output signal. After the type of output signal was determined, a bridge network was designed to adjust the size of the output signal to fit the telemetry system.

After each of the units had been checked, its output signal was run directly into the Pulse Amplitude Modulation system. The recording system was then adjusted to give the proper reading for a 0 to 5 volt reference. Each of the four hygrometers' recording channels was calibrated against the individual instrument's calibration.

The Bendix refractometers were also checked upon arrival. Proper voltages were applied, and the output signal was connected to a frequency counter to determine the basic frequency of each unit. A filter network was established for each refractometer to eliminate stray counts from other signals.

The Goldsmith Vapor Trap was fabricated in such a manner as to be nearly the same as the original units. The trap was leak tested to insure that no leaks existed in the trap or in any of the seals. After assembly and leak detection, the vapor trap was tested in an altitude chamber to determine airflow and collection ability. A life test on the liquid nitrogen supply showed that the liquid would last for 24 hours.

The Dual Molecular Sieve unit, obtained under Contract No. AF 19(628)-338, was assembled and prepared for operation.

## B. Environmental Test

After completion of the preliminary sensor checkout, the hygrometers and refractometers were tested in an environmental chamber. The chamber is a 6-ft diameter cylinder, 6 ft long that has a capability of simulating altitude pressures up to 300,000 ft and temperatures down to -65 C. Each of the sensors was placed in the environmental chamber. The proper input voltages were supplied, and each sensor's output was fed into a suitable measuring device. The two refractometer outputs were fed through a switching circuit which alternated sending them through a filter network into a frequency counter. One of the refractometer units gave a very noisy signal during the instrument checkout before the environmental test. As a result, this unit was not tested in the chamber.

During a preliminary pump-down of the environmental chamber, erratic behavior of the second refractometer was noted. When the chamber was opened, a leak in the chamber's cooling system was discovered, to which the irregular operation of the refractometer was attributed.

The four hygrometers were placed in the environmental chamber with the refractometer for the cold test. The test procedure was to cool the chamber and to monitor and compare the output of the hygrometers. After a temperature of -56 C was reached, the chamber was pumped down to a pressure altitude of 83,000 ft. A comparison of the frost points indicated by the instruments during this operation is shown in Table I.

Since both Honeywell units read the same in the chamber, their data are recorded as one in the table. It can readily be seen that the Ballistic Research Laboratories and Honeywell frost point units agreed quite well and that the Bendix unit lagged behind slightly. This was attributed to the lack of ventilation available for the Bendix unit in the test chamber.

During the environmental tests the actual flight telemetering system was used. The hygrometers used a 30 kc subcarrier system that added stray counts to the refractometer signal. This was due to the proximity of the basic refractometer frequency of 40 kc. As a result, the refractometer output was changed from  $f_d/2$ , 40 kc, to  $f_d$ , 80 kc, making it much easier to filter out the 30 kc subcarrier noise.

Table I. Environmental Test, Frost-Point Data

Time	Altitude (ft)	BRL <sup>1</sup>	MH <sup>2</sup>	Bendix
1410	0	+1.0	+1.7	—
1435		-7.5	-13.5	-7.5
1445		-16.0	-17.0	-14.0
1510		-27.5	-29.0	-25.0
1520		-37.0	-37.0	-32.5
1535		-40.0	-42.5	—
1550		-45.8	-45.4	-42.0
1610		-48.8	-49.0	-44.5
1620		-48.5	-50.0	-45.0
1630		-50.0	-52.0	-48.0
1650		-53.5	-54.5	-51.5
1700		-53.0	-54.0	-51.5
Stopped cooling - started pumping				
1720	2,000	-56.0	-55.0	-53.0
1730	10,000	-59.0	-57.0	-55.5
1735	16,000	-60.8	-58.0	-57.0
1740	24,000	-59.0	-58.9	-58.5
1840	83,000	-61.0	-60.0	-60.5

<sup>1</sup>Ballistic Research Laboratories

<sup>2</sup>Minneapolis Honeywell

### C. Preflight Group Testing

Upon completion of the environmental tests, the sensors were placed on the gondola for final testing. This test was designed to determine whether there was any interference between the individual units in their operation and data transmission, and, if so, to allow its elimination.

There was an indication of some RF interference in the Honeywell hygrometers. This was found to be originating from the 225 Mc data-transmitting signal and was eliminated by covering all of the Honeywell leads with aluminum tape. Interference in the one Bendix refractometer reoccurred. This was reduced, but not eliminated, by shielding the refractometers and by rearranging the transmitting antennas.

No difficulties were encountered with the Bendix or Ballistic Research Laboratories hygrometers during final group testing.

Present at these tests were T. Palmer and L. Fisher, Air Force Cambridge Research Laboratories; J. Ballinger, Minneapolis Honeywell; T. Mohan and R. Farrah, Bendix Corporation; and E. Pybus and W. Kramer of Ballistic Research Laboratories.

## IV. FLIGHT OPERATIONS

A balloon flight involves three separate operations--assembly of ground support and balloon-borne equipment; last minute checkout preparations of the entire system; and the actual launch, flight operation and recovery.

### A. Preflight Equipment Checks

Prior to our launching the flight system, the gondola and sensors were taken to the flight center for a final checkout. This included actual telemetering of data from the sensors to ground equipment that would be used during the flight. A block diagram of the flight instrumentation is shown in Figure 1, and that of the ground receiving equipment in Figure 2.

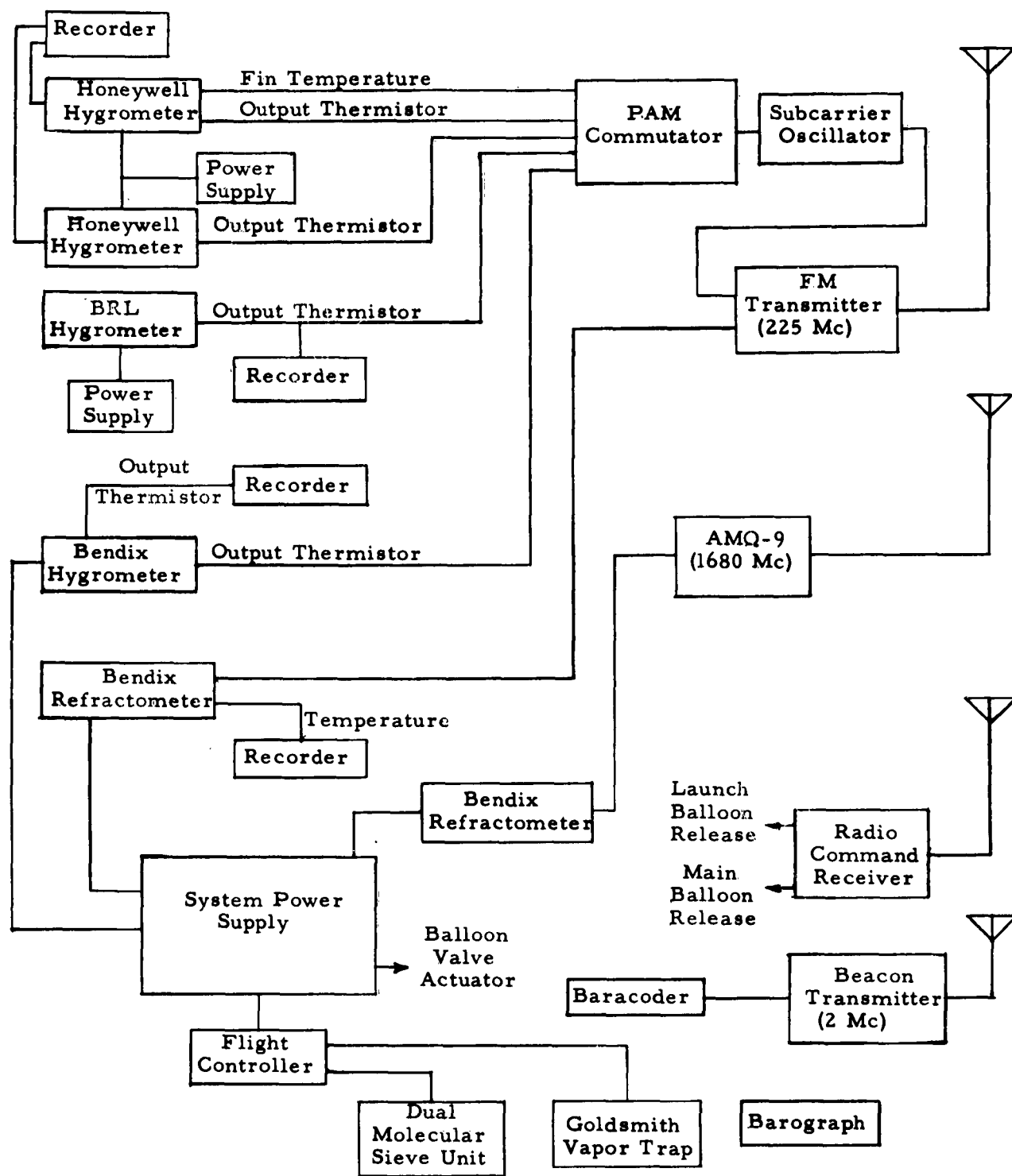


Figure 1. Block Diagram of Airborne Instrumentation

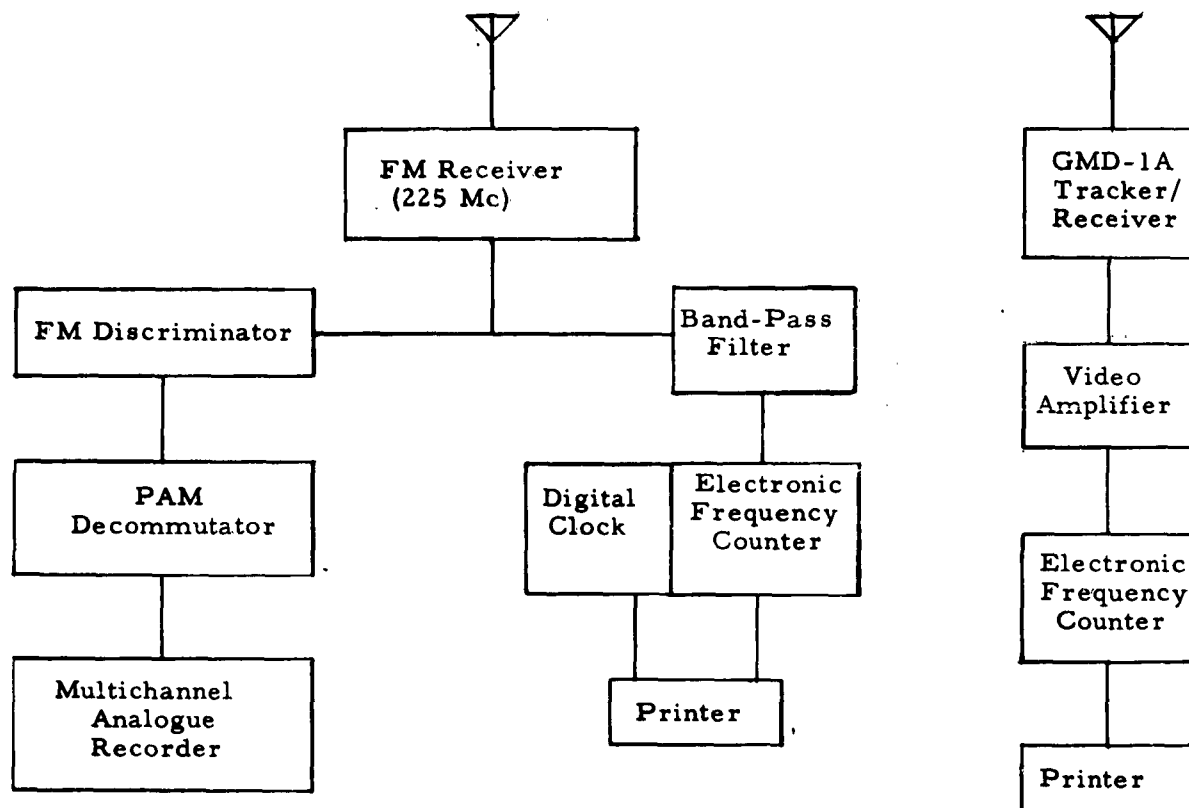


Figure 2. Block Diagram of Ground Support Instrumentation

The arrangement of sensors can be seen in Figures 3 and 4. Each sensor, as well as the air inlet to the Dual Molecular Sieve unit and Goldsmith Vapor Trap, was 8 ft from the center of the package. An aluminum box was designed for the batteries, control instruments and recorders. These items were placed inside the box in the center of the gondola, and the box was closed. The blowers of the Dual Molecular Sieve unit and Goldsmith Vapor Trap were equipped with ducts such that when turned on during float, they were exhausted upward 6 ft from the center of the gondola. To help reduce balloon-borne contamination, the package was placed 500 ft below the parachute and balloon.

A GMD-1A receiver was used to receive the refractometer signal as transmitted by the AMQ-9 transmitter.

The adsorbent for the Dual Molecular Sieve unit was prepared in advance of the flight. Two canisters were filled with adsorbent for use as controls. Two additional canisters were filled and, with two prepared empty canisters, were placed on the Sieve unit. The Goldsmith Vapor Trap had been heated to 400 C and evacuated the night before the flight. Just before the launch, liquid nitrogen was placed in the Goldsmith Trap's dewar.

After all the instruments and sensors had been attached to the gondola, each sensor was turned on, one at a time. Interference in the signal from each unit was located and reduced as much as possible. At the conclusion of this test, the entire flight train was taken out to the flight line. Again, the entire system was turned on, one unit at a time, to determine if transporting the equipment from the flight center had caused any problems.

Upon reaching the flight line, a number of difficulties arose. A short in the Ballistic Research Laboratories unit caused a component failure which could not be replaced before the flight. The unit remained on the flight for temperature measurements. The refractometer interference noted above again became so large that it blocked out all other data transmission. The original flight plan called for alternating the two refractometers on the 1680 and 225 Mc transmitting systems. However, the only way to reduce the data interference to an acceptable level was to place the signal from the "dirty"

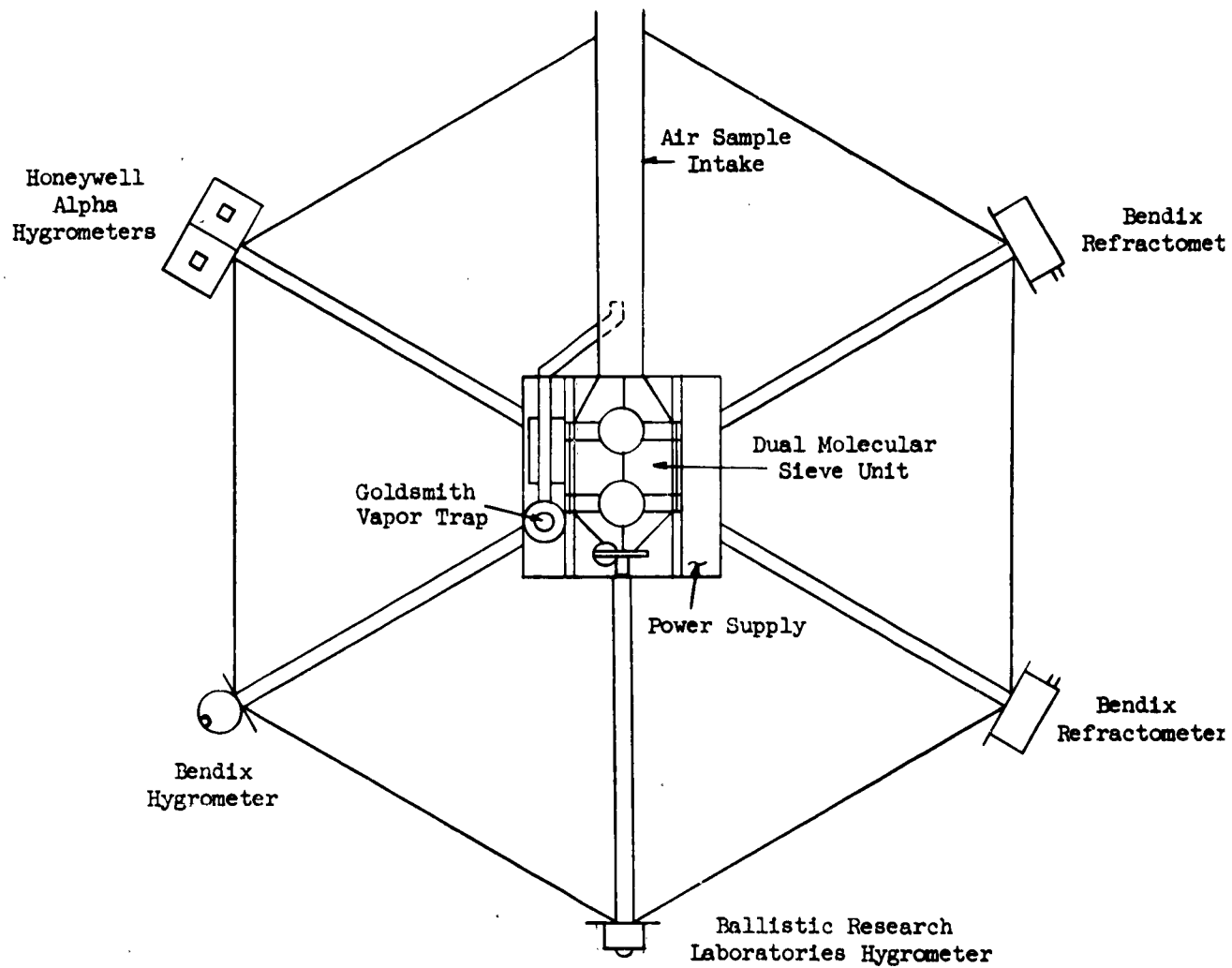


Figure 3. Arrangement of Sensors, Top View

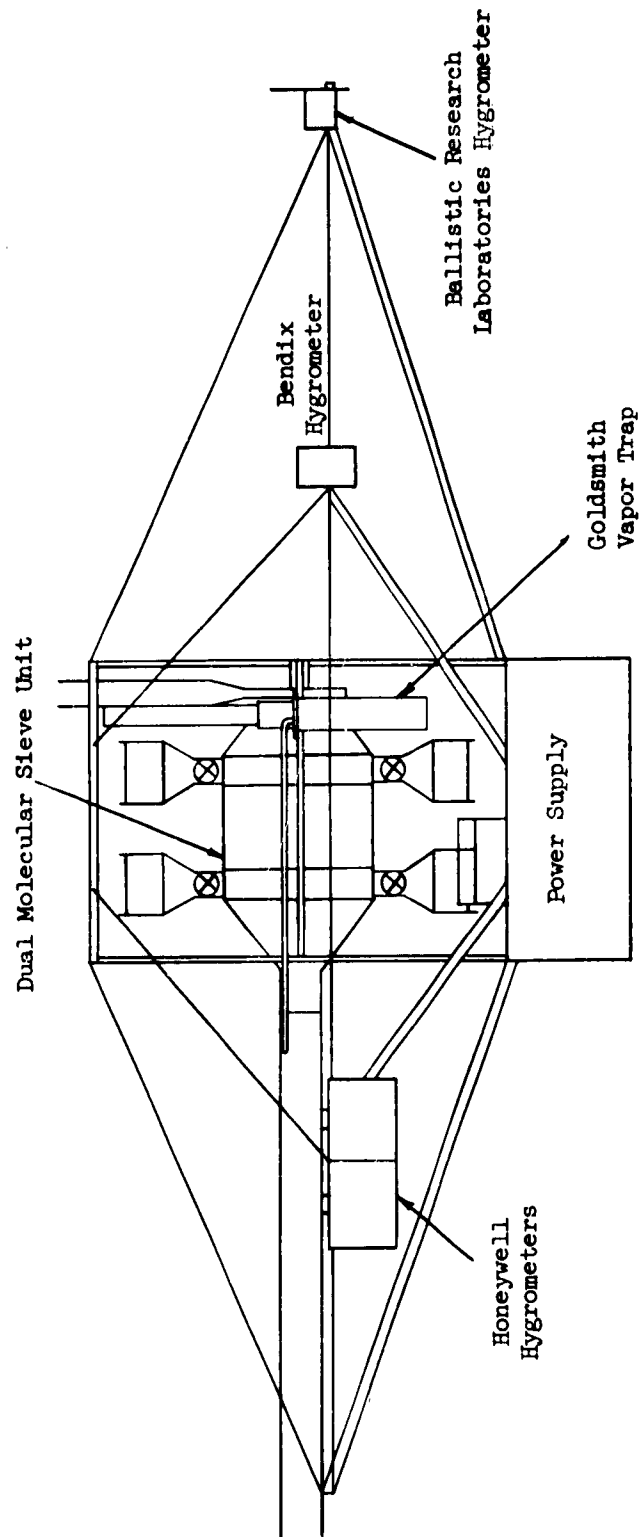


Figure 4. Arrangement of Sensors, Side View

refractometer on the 1680 Mc system and the "clean" refractometer on the 225 Mc system for the duration of the flight, instead of alternating them.

With each receiving and transmitting instrument checked, the flight system was ready for launch. The unexpected length of final checkout time had delayed the flight and lowered battery voltage.

#### B. Launch Procedures and Flight

A dual balloon launch system was used on this flight rather than a single balloon-truck launch due to the extremely long (500 ft) flight train. This launch system allows launches in higher ground winds than the truck launch. The main balloon, with the parachute attached to its base, is placed upwind of the package. A small, launch balloon is placed directly over the package with the package attached to both balloons. Each balloon has the same free lift. The main balloon is launched first. As the balloon rises and the load line is picked up, the load and launch balloon are released. With no load, the main balloon rises faster than the launch balloon, taking up the slack in the load line. When the load line is properly oriented, the load is released from the launch balloon and the flight continues.

The main balloon was launched at 9:17 AM CST on October 17, 1962 from New Brighton, Minnesota. During the delays caused by the refractometer interference, the ground winds increased to 15 to 18 knots, causing an unusually high strain on the inflated balloon. In addition, the ground winds had shifted slightly between layout and launch. This wind shift caused the load line to slide across the launch surface, catching on the ground anchor used to hold the launch balloon prior to launch. Since the main balloon had more momentum than the launch balloon, it pulled the launch balloon and load down until it hit the ground. This arrested the motion of the main balloon and allowed the load to start to rise again. Before the process could be repeated, the load line freed itself from the ground anchor and the balloon system ascended. As soon as the main balloon had taken up the slack in the load line, the launch balloon was released.

At "launch impact" the AMQ-9 transmitter was knocked from the package, canceling the signal of the "dirty" refractometer. The Bendix hygrometer struck the ground at launch, was disabled, and did not function during the flight.

The balloon ascended to its float altitude of 80,700 ft at an average rate of rise of 624 fpm, but remained there for only 30 minutes before it started a slow descent. At 2:25 PM CST the balloon flight ended with an impact 185 miles east of Minneapolis in 20 to 25 knot winds. As a result of the strong ground winds at impact, the tension switch that was to release the balloon did not actuate. The main load struck the ground four times before coming to rest in a grove of trees, having scattered equipment along the way. A considerable amount of damage was done to the equipment.

## V. FLIGHT RESULTS

Due to circumstances immediately prior to and at the launch, no data were received from the Ballistic Research Laboratories and Bendix hygrometers or from Serial No. 3 Bendix refractometer. In addition, a relay on the Dual Molecular Sieve unit failed to operate. This relay failure caused contamination of the adsorbent, invalidating any results that might have been obtained from this unit.

Data were obtained from the second refractometer, both Honeywell hygrometers and the Goldsmith Vapor Trap. The refractometer data for the complete flight is plotted in Figure 5. They were reduced from the telemetered frequency by applying the proper conversion factor and a temperature correction. This correction was determined after the flight by assuming a refractive index change of 260 N units from ground level to 80,000 ft. The original temperature correction had been determined in a cold box without considering any radiation heating effects. As a result, discussions with the manufacturer led to a correction of 2.6 N units per C for unit No. 4.

The refractometer data are reasonable (that is, they appear to follow data given by B. R. Bean, et al<sup>4</sup>) until a pressure of approximately 480 mb. At this point the index of refraction increases and becomes too large, instead

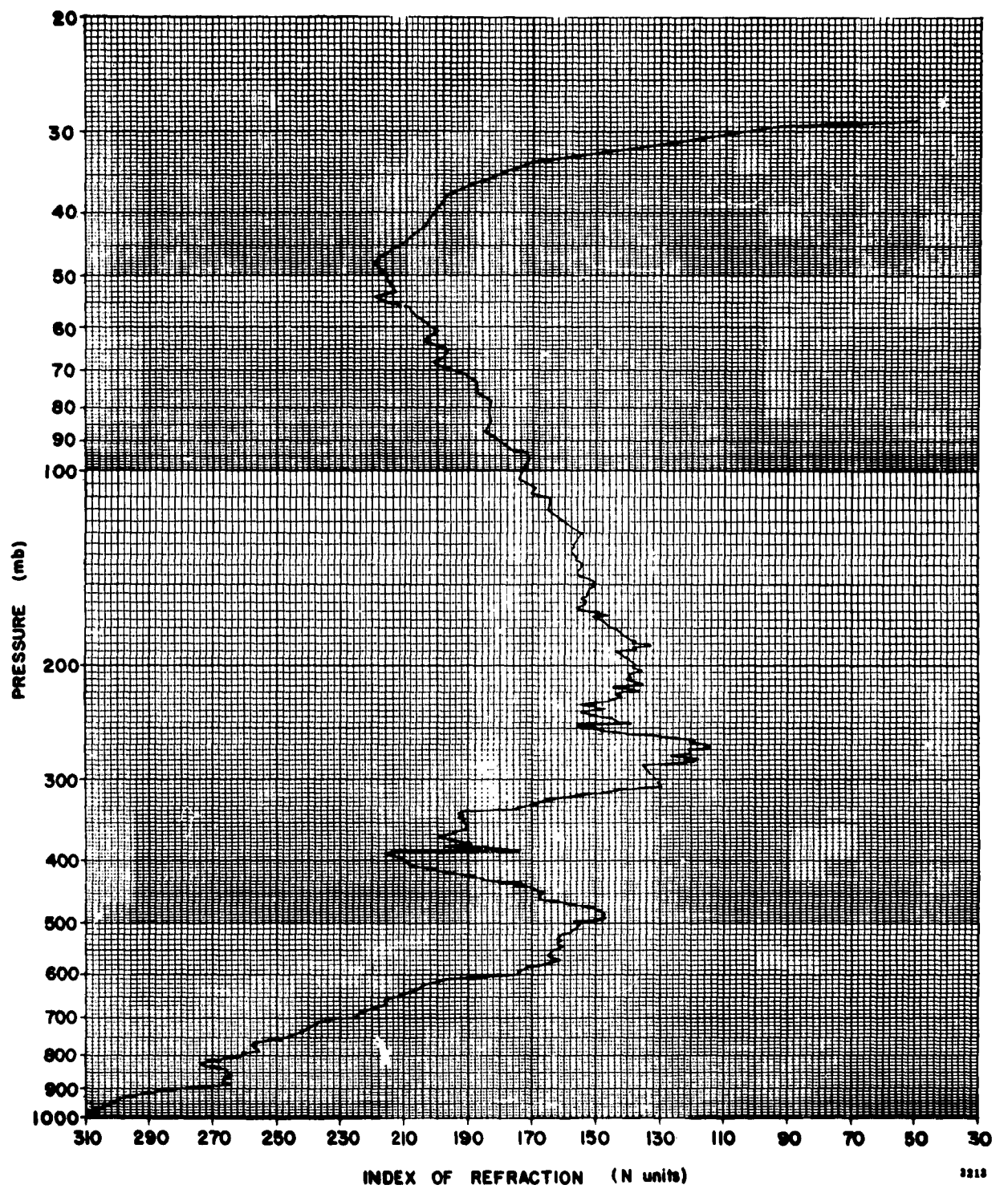


Figure 5. Refractometer Data

of decreasing as expected. The index of refraction indicated by the refractometer starts decreasing again at 390 mb until it approaches a reasonable value of 114 N units at 260 mb. Here the index of refraction again starts to increase until a value of 220 N units is reached at 48 mb. It then decreases to a value of 50 N units at 29 mb, which is the value assigned for the 260 N unit change. No explanation can readily be made to explain this strange behavior of the refractometer. There appeared to be nothing wrong with either the refractometer or the telemetering system during the flight. At final impact both refractometers were partially damaged so that they could not be operated without repair.

In addition, while the package was at altitude, the refractometer indicated several large-scale changes of refractive index. Discussions held with the manufacturer of the instrument led to the belief that these may have been caused by solar heating of the instrument.

A closer examination of the refractometer performance to 480 mb may be obtained from Figure 6. An index of refraction lapse rate curve\* is plotted utilizing lapse rates of temperature taken from the 1200 GMT St. Cloud radiosonde data, and the frost point from the alpha hygrometer data. In addition, the refractometer data, alpha frost-point data, and 1200 GMT St. Cloud temperature data are shown. Examination of the two refractive index curves indicates the following: gross lapse rate shapes are similar; in general the magnitudes of deflection and slopes of the two curves differ; the sign of the slope of each curve is the same at any given point; the maximum deviation is 22 N units, the minimum deviation is zero, the mean deviation is 9.4 N units, and the standard deviation (rms) is 11.64 N units; small-scale variations appear, but it is not known if these are real or instrument error. These indications are specific to this case, and can only imply rather than state faults.

Data were received from both Honeywell alpha hygrometers. Since thermistors tend to age and the original calibration was made approximately one year earlier, the two instruments were recalibrated after recovery. The two calibration curves were similar differing at no point by more than two

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\*The Smith-Weintraub formula  $N = \frac{77.6}{T} \left( P + \frac{4810 e}{T} \right)$  was used for these calculations.

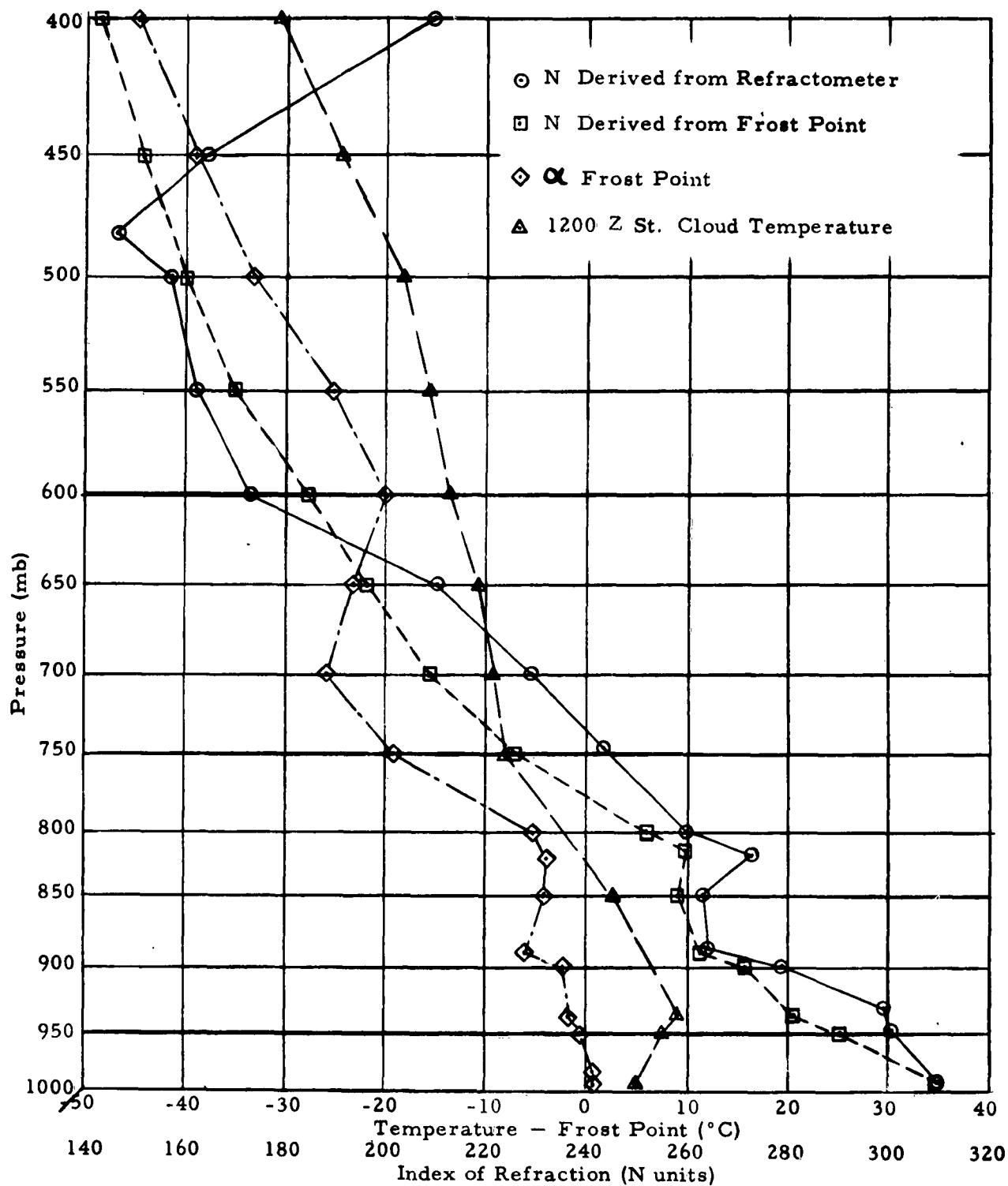


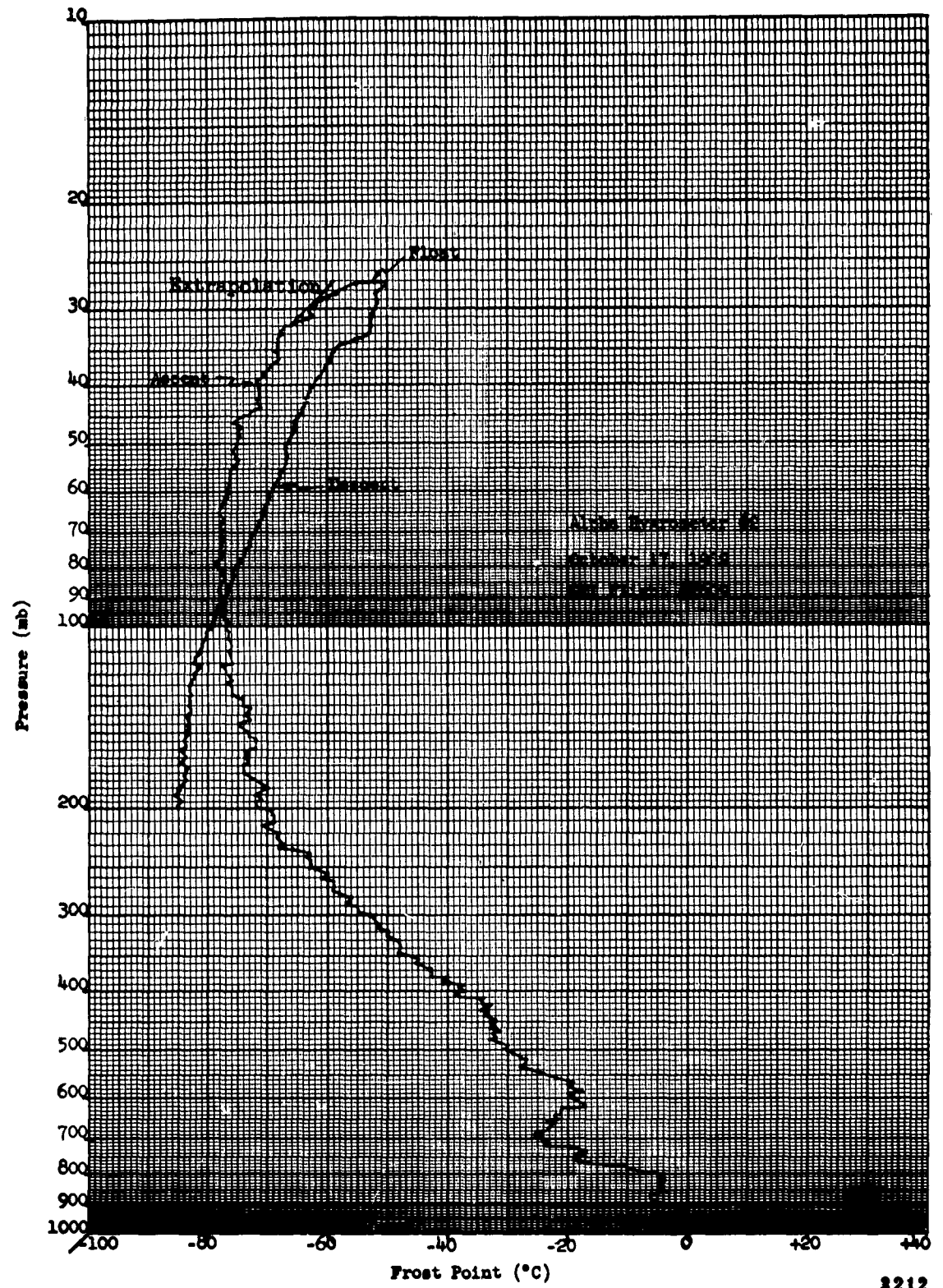
Figure 6. Comparison of Experimental and Calculated Index of Refraction, Frost-Point, and Ambient Temperature Data

degrees. The recalibration curve was considered by Honeywell personnel to be more reliable than the original calibration and was used in determination of frost points and calculation of mixing ratios. Each of the units contained two thermistors, one for telemetering data and the second for onboard data recording. Although each instrument showed slight variations in the second-to-second data, all distinct changes were recorded exactly alike by the four thermistors.

A plot of the Honeywell No. 5 unit is shown in Figure 7. The frost points determined on ascent are in general considered to be good points. These points appear to be high when compared with other data in the literature, but daily changes in air masses lead one to believe that these may be real. The frost point starts to rise rapidly as the system nears float altitude and continues to rise during the time at float. The former is caused by the slow ascent rate as the balloon levels off. This does not allow proper ventilation and allows contamination from the instrument's styrofoam. The latter is a result of large-scale contamination being desorbed from the instrument's styrofoam by solar radiation.

The alpha hygrometer's operation is limited by the temperature difference between the instrument's fin and the operating point (frost point) of the Peltier cooler. During the float period, solar radiation caused the fin to reach a temperature above the ambient temperature. As a result, at approximately 50 mb on descent the temperature difference between the fin and the frost point was greater than the instrument could produce. At this point the frost "spot" was lost, even though the cooler was on full cooling. Under full cooling, the instrument still could not form a "spot" of frost, resulting in the very dry frost points shown in Figure 7 at the low altitudes on descent.

Due to the above-mentioned sharp increase in indicated frost point near float altitude, the data immediately prior to and at float are suspect. A reasonable extension of the experimental data is therefore included in Figure 7 from the point of noted contamination. This extension was used in the comparison with Goldsmith Vapor Trap data. The average values of frost points obtained for selected pressures are shown in Table II.



3212

Figure 7. Frost-Point Data

Table II. Average Frost Points of the Two Alpha  
Hygrometers Obtained on 17 October 1962

Level (mb)	Frost Point (C)	Ambient Temperature (C)
900	-4	+9
800	-6	-5
700	-25	-9
600	-21	-13
500	-31	-18
400	-38.5	-31
300	-52.5	-47
200	-67.5	-54
150	-72	-56
100	-75.5	-62
90	-76	-62
80	-76	-61
70	-76	-61
60	-75	-60
50	-74	-59
40	-70	-58
30	-63	-57
28	-60	-57

The Goldsmith Vapor Trap was turned on after the balloon system had been at altitude (28 mb) for 10 minutes. The blower continued to run until the balloon reached an altitude of 78 mb, a period of 93 minutes. Pressures were determined from the telemetered barocoder signal. During this period the voltage on the system had dropped to a very low value. The actual value is unknown, although in order for the relay on the Dual Molecular Sieve unit to have failed, the voltage would have had to drop below 13 volts. As a result of the low voltage, the Goldsmith Vapor Trap sampled at a much slower rate than that anticipated. The trap collected 0.008 g of water from an air mass of 0.085 kg, yielding a mixing ratio of  $0.09 \pm 0.01$  g H<sub>2</sub>O per kg air. This is an average value over the sampled altitude of 28 to 78 mb, with the average being the actual value for approximately 30 mb as indicated by the alpha hygrometers.

An attempt was made to compare the water-vapor data determined by the Goldsmith Vapor Trap and the Honeywell hygrometers. Since the value determined by the Goldsmith Vapor Trap was an average value, an average value over the same altitude interval must be calculated from the alpha hygrometer data. The data obtained on descent were known to be false because of contamination from the instrument's styrofoam. The data obtained just prior to float were also doubtful since the balloon ascent rate had dropped too low.<sup>5</sup> Thus, an extrapolation of the ascent data was used to determine the actual frost point at 28 mb.

In order to eliminate known erroneous data, only the ascent data of the alpha hygrometers were used in determining the average mixing ratio over the 28 to 78 mb range. Using this data and calculating the mixing ratio for equal time intervals, adding these and dividing by the total time, we obtained an average mixing ratio for the 28 to 78 mb range as determined by the hygrometers. Hygrometer No. 2 provided a value of  $0.10 \pm 0.01$  g per kg, while hygrometer No. 5 provided one of  $0.12 \pm 0.01$  g per kg for the average mixing ratio. Since it is possible that the ascent data may be in error to some degree because of possible contamination by the balloon "wake", one would expect the ascent mixing ratio to be slightly higher than that of the descent. Thus, the mixing ratios obtained from the alpha hygrometer data are in close agreement with that obtained by the Goldsmith Vapor Trap.

Among the possible sources of contamination are balloon helium and the batteries. The helium used on the balloon flight was tested and found to have a frost point of -60 C. This is approximately the value obtained at float altitude. It is believed that the helium was not a major source of contamination on ascent since the balloon reached its theoretical float altitude at the theoretical ascent rate. However, failure of the balloon to remain at altitude for the proper length of time indicates that there was a hole in the balloon. In addition, 9 percent of the 21,600 cu ft of helium used were ducted at float. This could diffuse into the vicinity of the package while at float.

The possibility of a broken battery causing a large source of contamination has been examined because of the low voltage on the flight. If a battery had been broken due to the impact at launch, its activating fluid would have drained out. This would cause an open circuit in the power supply containing the battery. If this occurred in the main supply, the Goldsmith Vapor Trap would not have functioned. Since the Goldsmith Vapor Trap did function, this circuit must have been all right. In a like manner, all other circuits were checked out with the exception of three cells. From their location with respect to the other cells at launch impact, it does not seem likely that these would have broken.

## VI. CONCLUSIONS AND RECOMMENDATIONS

A replica of the Goldsmith Vapor Trap used in the United Kingdom was built and tested for use on a balloon flight for the purpose of sampling water vapor in the stratosphere. In addition to this unit, a Dual Molecular Sieve unit, four hygrometers, and two refractometers were tested and prepared for use on the same flight. Instrumentation was designed and assembled that would insure two separate data channels for each sensor in the event one channel should fail.

The balloon system was assembled, tested, readied for flight, and launched. Data were received from four of the instruments--the two alpha hygrometers, one refractometer, and the Goldsmith Vapor Trap. The data of the refractometer are plausible up to a pressure of 470 mb. However, upon comparison

with the frost-point profile the index of refraction data is not acceptable. The frost-point data as determined by the alpha hygrometers are considered valid on ascent until just prior to float altitude. From this point on, the frost-point data are erroneous because of contamination or inability of the instrument to reobtain a frost "spot". The Goldsmith Vapor Trap yielded an average mixing ratio of  $0.09 \pm 0.01$  g per kg over a pressure range of 28 to 78 mb. Although this unit sampled at a lower rate than desired, there is no indication that there was any contamination of the unit. This data compares quite favorably with the alpha hygrometer ascent data.

No known reasons for the implausible refractometer data have been developed and substantiated. There is a possibility that the refractometer is temperature sensitive after exposure to low temperatures for any length of time, and that the assumed temperature correction may not be linear. If true, these could be the cause for at least some of the refractometer's erratic behavior.

The major source of contamination of the alpha hygrometers' data was the water vapor that outgassed from the styrofoam associated with the hygrometers. This was only a problem immediately prior to and during the float period. During this period solar radiation heated the styrofoam, desorbing water vapor in the vicinity of the detector. The main portion of the ascent was not affected by solar radiation since the velocity of the package through the air kept the styrofoam from heating.

Due primarily to the extensive testing required to reduce cross-interference, especially among the refractometers, the battery voltage on the flight was low. This low voltage resulted in a number of problems. These included the Dual Molecular Sieve unit's not completing its cycle and the Goldsmith Vapor Trap's sampling at a low rate.

The program was a success in that data were received from four of the instruments that functioned on the flight, and a comparison of the three types of hygrometers was obtained in the environmental test. This test indicated that, under identical conditions of saturated air, each instrument indicated the same frost point. The test did not, however, indicate what would happen under operational conditions.

This program attempted to test a number of instruments to determine compatibility and to obtain and compare data from them with one balloon flight. Special problems were found when these sensors were tested together that were not apparent when they were tested individually. Good data comparison was obtained from the water-vapor instruments that functioned on the flight.

Contamination of water-vapor sensors and water-vapor sensitive instruments is extremely difficult to control. Significant contaminants include the balloon vehicle, instrumentation, batteries, parachute, exposed metal surfaces, styrofoam, and the instruments themselves. Precautions were taken to reduce the effect of each of these possible contaminants as much as possible. A 500-ft long load line was used between the parachute and sensor package to reduce contamination from both the surface of the polyethylene balloon and the parachute. All of the instrumentation and the batteries were enclosed in an aluminum box. No shock absorber was used on the gondola, and all styrofoam was eliminated except where required on the alpha hygrometers.

The amount of outgassing from various surfaces is dependent upon pressure and heating effects. Laboratory tests have shown that all types of polyethylene foam, open and closed-cell styrofoam, and sponge rubber "weep" after being placed in a chamber under reduced pressure. This "weeping" (or desorption of water) is dependent upon the amount previously adsorbed on the foam, but is visible even on "dried" material.

Further tests on outgassing of various materials are recommended. The various insulating materials described above and stainless steel and aluminum sheet and tubing should be compared in these tests in both an untreated and treated condition. The treatment could consist of coating surfaces with plastic sprays, polishing surfaces to reduce area, painting to decrease infrared absorption and heating and chemically treating. For the tests the items can be placed in a water-vapor saturated atmosphere and then dried to varying degrees prior to placement in an environmental chamber.

A laboratory type hygrometer could be used to determine the amount of water each item would desorb under various conditions of pressure, temperature, and thermal radiation, and combinations of these conditions. In

this manner, we could determine the best materials and the best methods of preparing these materials for minimal water-vapor contamination during balloon flights.

The problem of accurately measuring the water-vapor content and index of refraction of the atmosphere has not been decided by the one flight reported herein. There exists a definite need for 1) calibration of frost-point indicators against gravimetric devices under operational conditions, 2) comparison of different types of frost-point indicators under identical operational conditions, and 3) comparison of water-vapor sensitive refractometers with frost-point indicators under operational conditions to determine whether the instruments are functioning properly.

Due to the aforementioned requirements, and realizing the complex problems (compounded with each additional instrument) of bringing a number of instruments together, the following method of attack is recommended.

A series of research flights would be flown, each flight being restricted to a small number of sensors. Two gravimetric devices, along with one or two hygrometers of different types, would be flown to obtain a comparison of these units. Then a different combination of hygrometers and gravimetric devices, hygrometers and refractometers, or several different types of hygrometers would be flown to obtain similar comparisons. Each flight would have the same float altitude, ascent rate, and descent rate. As many flights as is reasonable would be flown concurrently to obtain relationships between instruments on different balloons. A series of flights with various sensor combinations would yield significant data on the accuracy, precision, and reliability of these different instruments under operational conditions.

## VII. PROJECT PERSONNEL

Personnel who participated in this program were Stephen Rohrbough, Project Scientist, Sheldon Steinberg, and Richard Conlon. In addition, John Ballinger of Minneapolis Honeywell provided invaluable assistance in the reduction and interpretation of alpha hygrometer data.

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General Mills, Inc., St. Paul, Minnesota  
A STUDY OF HIGH ALTITUDE WATER-VAPOR DETECTORS,  
By S. Rohrbough. Scientific and final report  
31 March 1963. 27 p. Incl. illus. and tables. (Rept. No. 2365).  
(Contract AF 19(628)-483)  
(AFCRL-63-407) Unclassified Report

DESCRIPTORS: Hygrometers, Refractometers, Gravimetric  
water-vapor collector, Balloon flight, Frost point, Mixing ratio

This report describes the research and engineering required to prepare a sampling system for making water vapor and index of refraction measurements in the atmosphere. It covers the instrumentation, equipment testing, flight description, and results of the flight, and includes conclusions and recommendations.

The purpose of the flight to 80,700 ft was to correlate data received from several different types of water-vapor indicators. These included four hygrometers (two alpha type and two optical type) and two gravimetric water-vapor traps (the Dual Molecular Sieve unit and Goldsmith Vapor Trap). In addition, two microwave refractometers were flown to see if the two units functioned properly under operational conditions.

Index of refraction data were obtained only from one unit; these followed published data for the first portion of the flight, but wandered radically during the latter half. The two alpha hygrometers functioned properly during ascent, but their data were erroneous because of contamination during descent. Their data are plotted in both graphical and tabular form. The Goldsmith Vapor Trap sampling was at a slower rate than expected but yielded a mixing ratio of  $0.09 \pm 0.01$  g per kg over an altitude range of 28 to 78 mb.

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